# Risk In Cost Estimating

## General Introduction

## &

## The BMDO Approach

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# Introduction

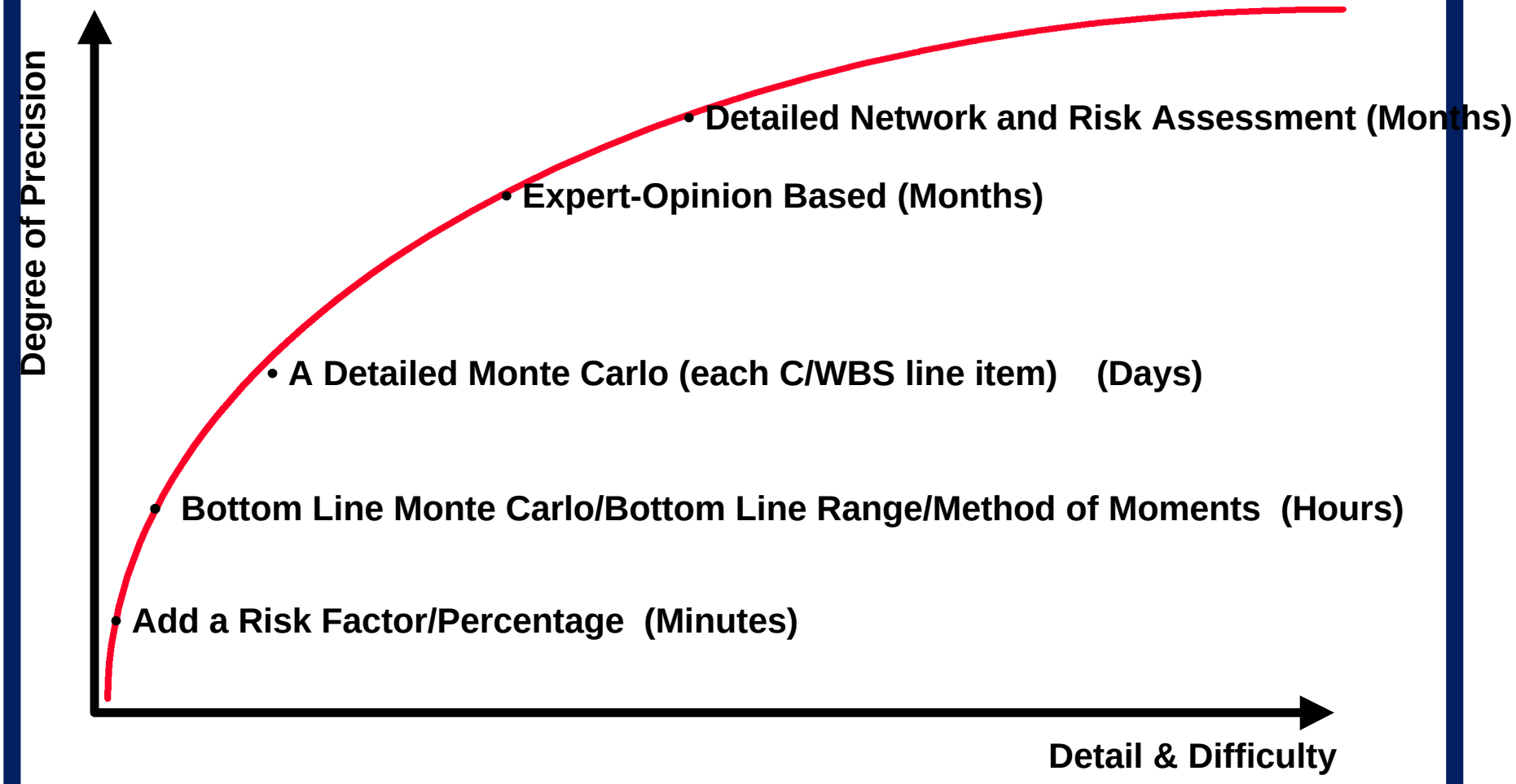
- Risk is a significant part of cost estimation, and is used to adjust budgets for historical cost growth.
- Incorrect treatment of risk, while better than ignoring it, creates a false sense of security.
- This brief will define risk, discuss it in general, and describe several approaches to estimation.
- The brief will conclude with a detailed examination of the BMDO method

# Definitions

- Cost Growth: Increase in cost of a system from inception to completion.
  - Often expressed as %
  - Expressible in Phases, or as LCC
- Cost Risk: The funds set aside to cover predicted cost growth.

**In other words:**
**Cost Growth = actuals**
**Cost Risk = projections**

# Risk Assessment Techniques



# The Monte Carlo Technique

- **Probability distributions are determined for the each WBS item.**
  - **Cost of WBS, or duration of event**
- **A random draw from these distributions is taken, one per item, and added up … this is repeated thousands of times to determine the average (and other statistics.)**
- **We use Monte Carlo because the math of determining the average for the whole estimate is quite complicated, unless it is just a simple sum.**

# Common Issues in the Monte Carlo Technique for Risk

(Answers to Questions That Often Come up)

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# Monte Carlo Distribution Choices

- **Triangular**
  - Most common
  - Easy to use, easy to understand
  - Modes do not add
- **Normal**
  - Second choice
  - Best behavior, most iconic
  - Allows negative costs and durations, which spook some users
- **Beta**
  - Rare
  - Solves negative cost and duration issues
  - Rough math
  - Many parameters

# Correlation of Elements

- **Correlation**
  - **Increases dispersion**
  - **Shifts the mean**
  - **Hard to model well.**
- **Ways to model correlation**
  - **Choleski factorization**
  - **Estimating correlations**
  - **Functional correlation[1]**

*1 An Overview of Correlation and Functional Dependencies in Cost Risk and Uncertainty Analysis*, DoDCAS 1994**, R. L. Coleman, S. S. Gupta**

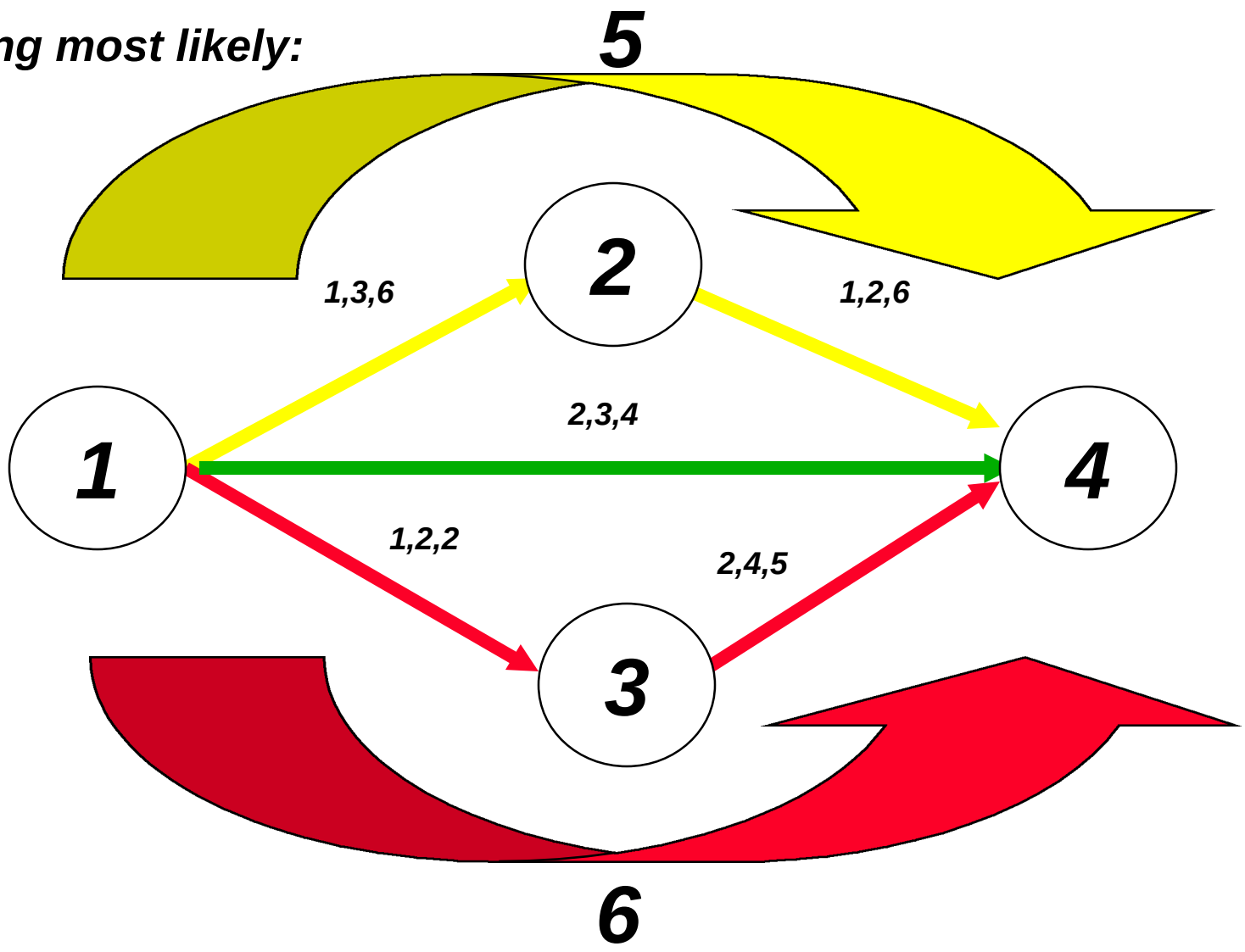
# Detailed Network Method

## Monte-Carlo Technique

- **Requires a full PERT-type chart of the program**
  - ***Cannot* be simplified and still be *right***
- **The durations of the PERT chart are made stochastic**
  - **Actually, PERT already collects enough information to do this: least, most likely and greatest duration**
  - **–PERT usually assumes the Beta distribution, but the Triangular is another choice**
- **The stochastic answer is compared to the deterministic answer**
  - **The difference is the schedule slip risk**
  - **Various types of statistics are available, e. g., mean, confidence interval, etc**

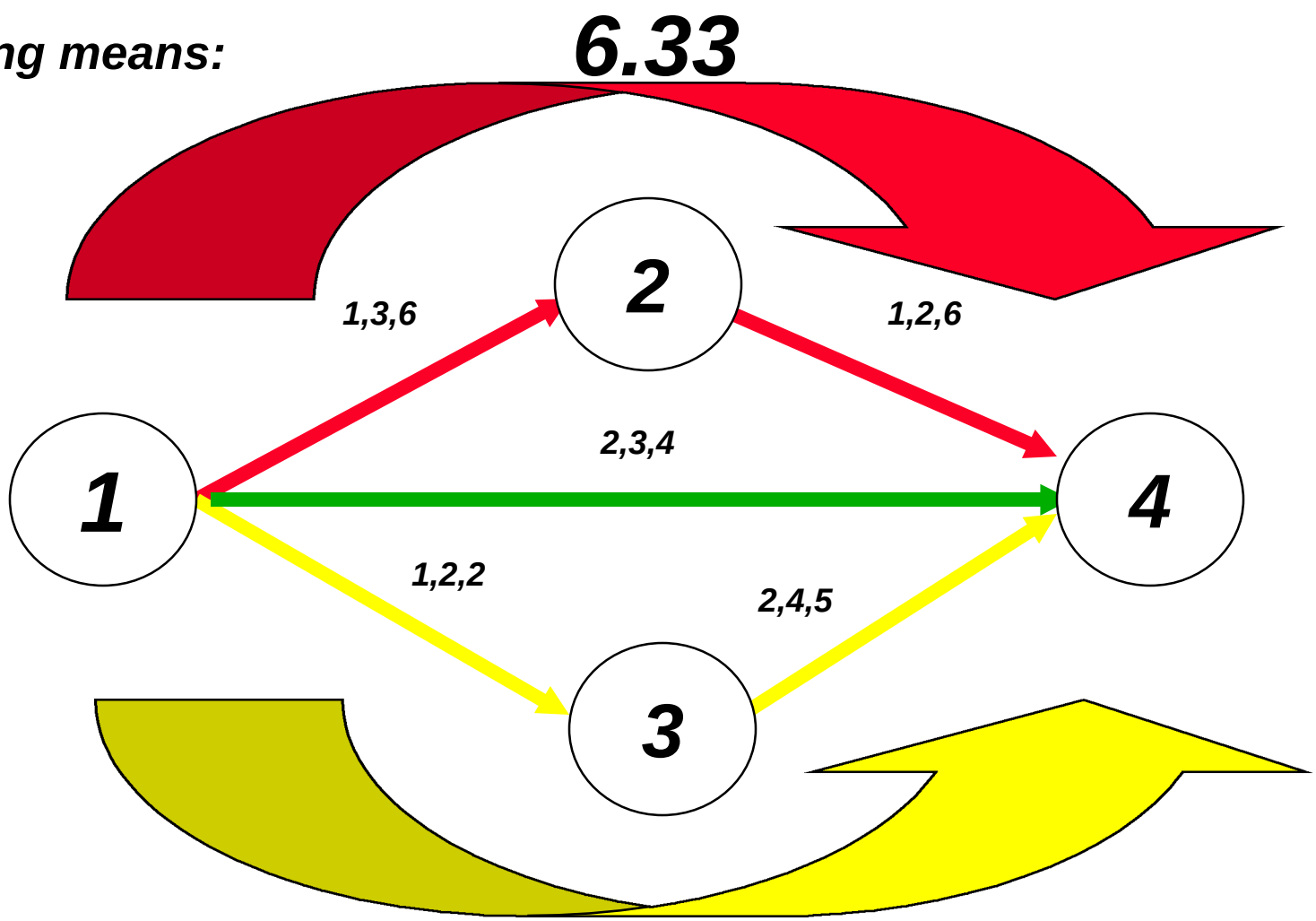
# "Detailed Network" Illustration

***Adding most likely:***



# "Detailed Network" Illustration

***Adding means:***



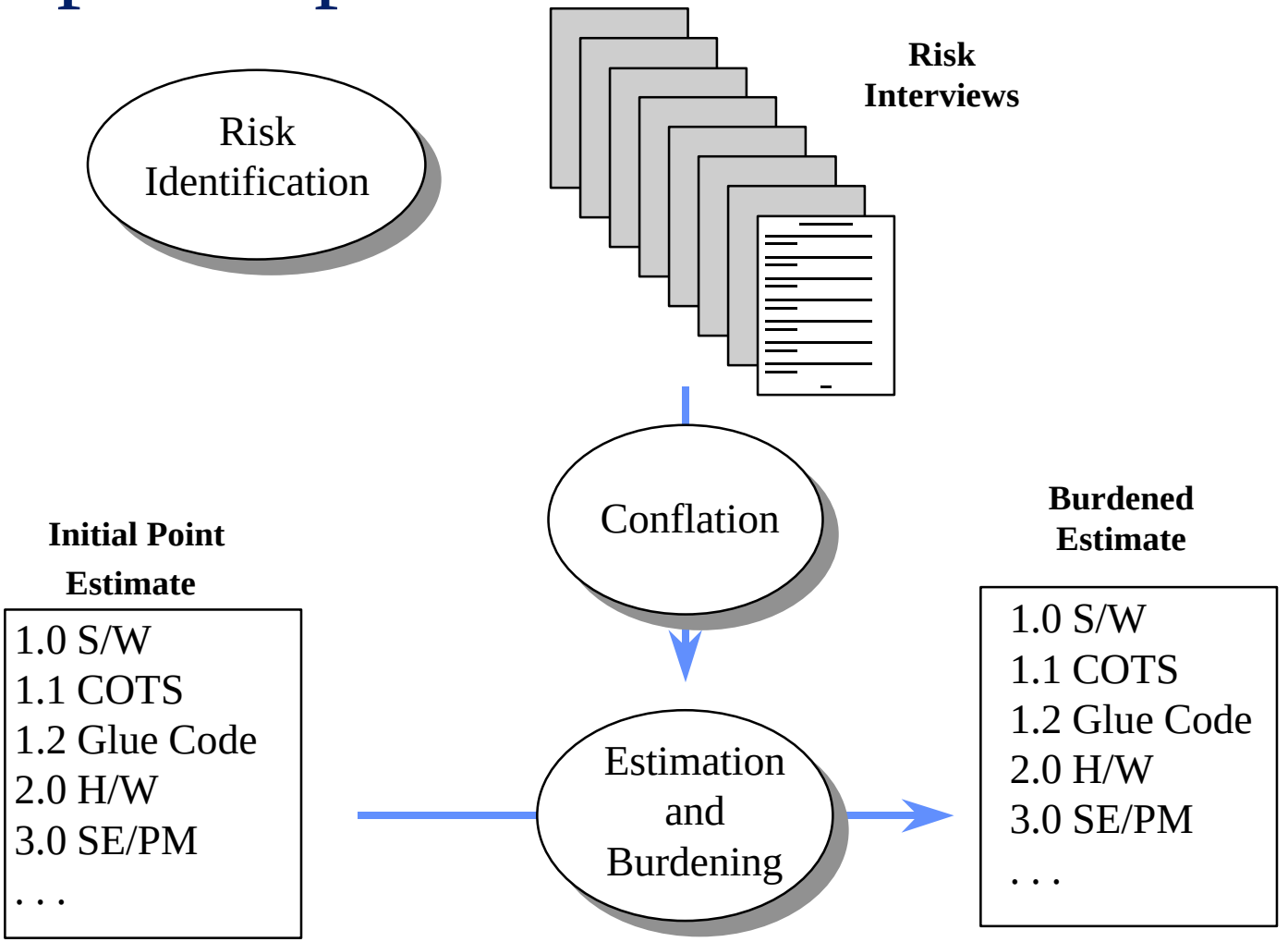

***… the answer is different!***

# Expert-Opinion-Based Cost Method

## Monte-Carlo Technique

- **Expert Opinion-Based methods rely on surveys or interviews of technical experts.**
- **Interviews usually ask the expert to determine a lowest, most likely and highest number for each WBS cost.**
  - **These are almost always mapped converted to triangles, and a Monte Carlo is conducted.**
- **Applicability and currency issues do not arise.**
- **Problem is whether technical experts have any real sense of how much things cost, or how much costs can rise.**

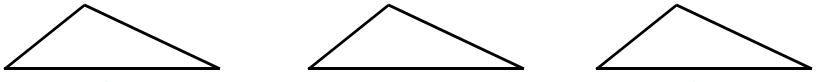
# Expert-Opinion Risk Model Process

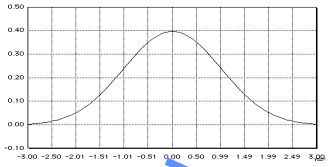



*Risk Analysis of a Major Government Information Production System, Expert-Opinion-Based Software Cost Risk Analysis Methodology*, DoDCAS 1998 Outstanding Contributed Paper, and SCEA/ISPA International Conference 1998 Overall Best Paper Award, N. L. St. Louis, F. K. Blackburn, R. L. Coleman

# Conflation of Expert Interviews

**Merge**
Multiple estimates of the same effect

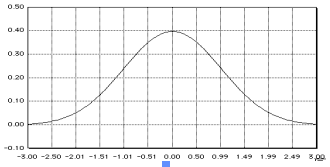




**Add**
Separate effects

Three separate, triangularly distributed random numbers are drawn and **averaged**.

Two separate, random numbers are **added**. One is a newly drawn triangular, the other is the result of the previous 3 triangles.

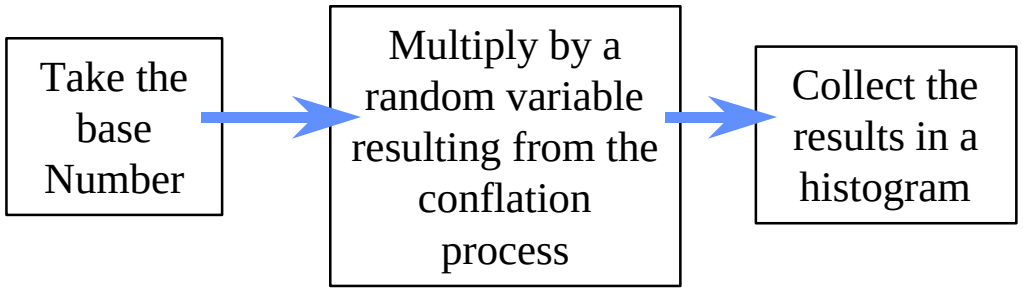


A similar process is repeated 1000 times, for each line of the WBS

**Output**
One number feeds into the model for each WBS element

# Estimation and Burdening

Steps:




Example:

| WBS | Initial Point Estimate | Conflation Result | Burdened Result |
|---|---|---|---|
| 1.0 S/W | 100M | | 148M |
| 1.1 COTS | 80M | 1.1 | 88M |
| 1.2 Glue Code | 20M | 3.0 | 60M |
| 2.0 H/W | 10M | 1.2 | 12M |
| 3.0 SE/PM | 11M | | 16M |
| Total | 121M | | 176M |

Some elements are roll-ups

Some elements are factors off of others

The result is a burdened estimate

# Historically-Based Method

## Monte Carlo Technique

- **Most historically-based methods rely on SARs**
  - **Adjusting for quantity: important to remove quantity changes from cost growth**
  - **Beginning points: The richest data source is found by beginning with EMD**
- **C/SCSC (EVM) data is also potentially useable, but re-baselined programs are a severe complication.**
- **"Applicability" and "currency" are the most common criticisms**
  - **Applicability: "Why did you include *that* in your data base?"**
  - **Currency: "But your data is so *old*!"**

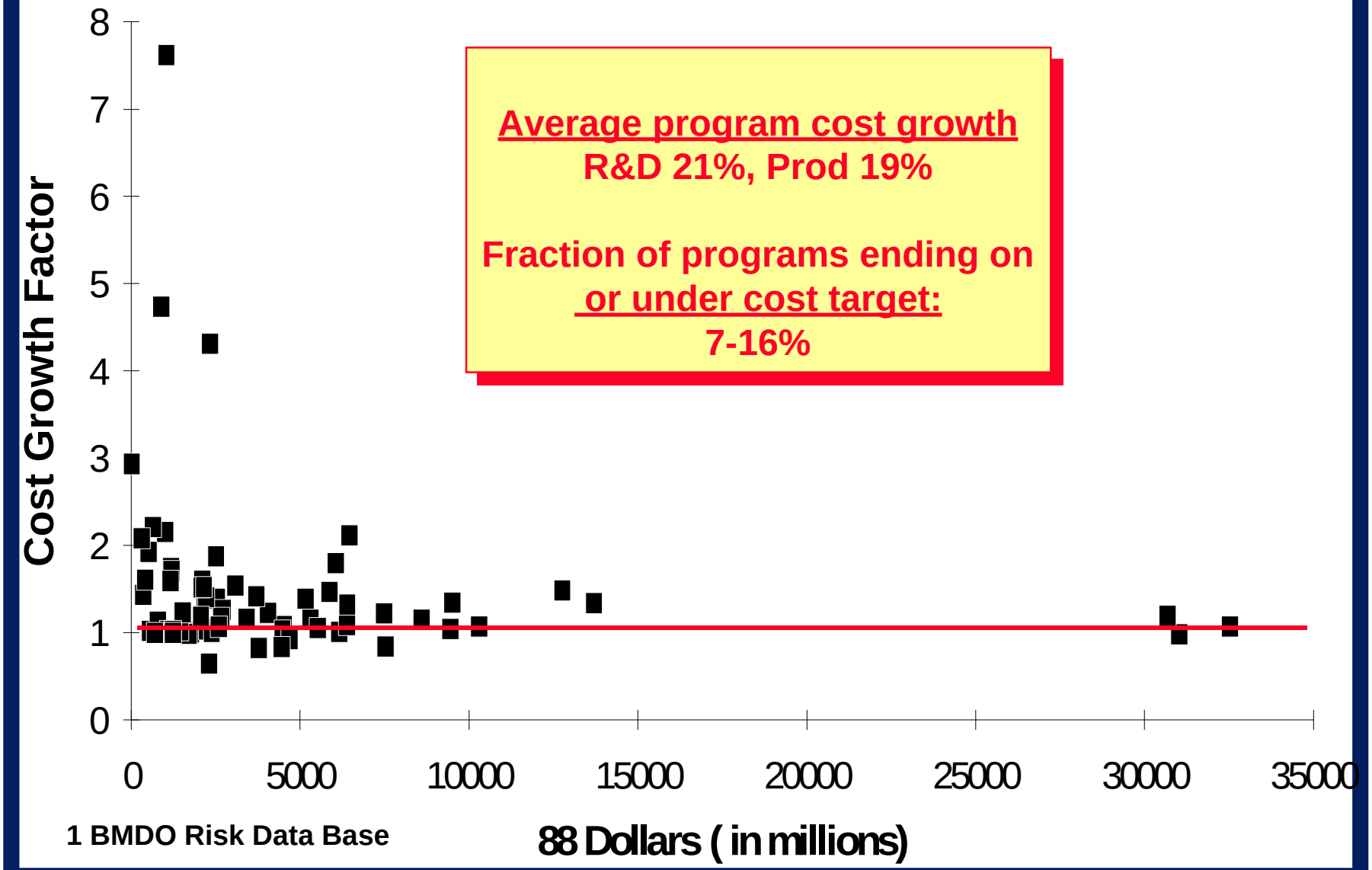
# Applicability and Currency

- **Applicability: "Why did you include *that* in your data base?"**
  - **Virtually all studies of risk have failed to find a difference among platforms (some exceptions)**
  - **If there is no discoverable platform effect, more data is better**
- **Currency: "But your data is so *old*!"**
  - **Virtually all studies have failed to find a difference in cost growth patterns across time**
  - **Data accumulation is expensive**

# Historical Basis

## What does history look like?

# Historical[1] Cost Growth




**Average program cost growth**
**R&D 21%, Prod 19%**

**Fraction of programs ending on or under cost target:**
**7-16%**

# Historical Cost Growth

| | Raw Average | | | $ Wtd Average | | | | During Prod |
|---|---|---|---|---|---|---|---|---|
| Source | Tot | R&D | Prod | Tot | R&D | Prod | N | Prod |
| RAND 93: | 1.30 | | | 1.20 | **1.25** | **1.18** | 100+ | **1.02** |
| CAIG 91: | 1.33 | 1.40 | 1.25 | 1.21 | **1.24** | **1.19** | 27 | |
| TASC 94: | | 1.49 | 1.54 | | | | 20+ | |
| TASC 96: | | 1.43 | 1.55 | | **1.21** | 1.35 | 14 | **0.99** |
| Christensen 99: | | | | 1.09 | **1.14** | | | **1.06** |

***MSIII***

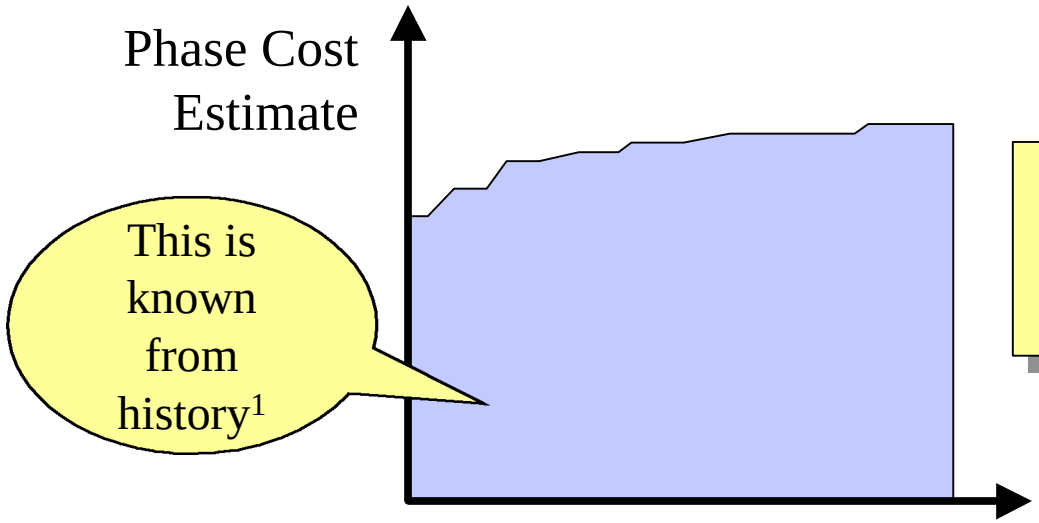
**This chart presents data from different eras & different data base subsets**
**The message it conveys is a general similarity, not precise equality**

**1. All data are from DoD SARs, under <u>generally</u> the same rules and procedures, except for Christensen.**
**2. Christensen data is EVM Data, which includes re-baselining.**
**3. This cost growth data includes growth due to "Cost Estimating Errors".**
**4. RAND Data and CAIG Data are from MS I, TASC data is from MSII.**

# Risk & Maturity

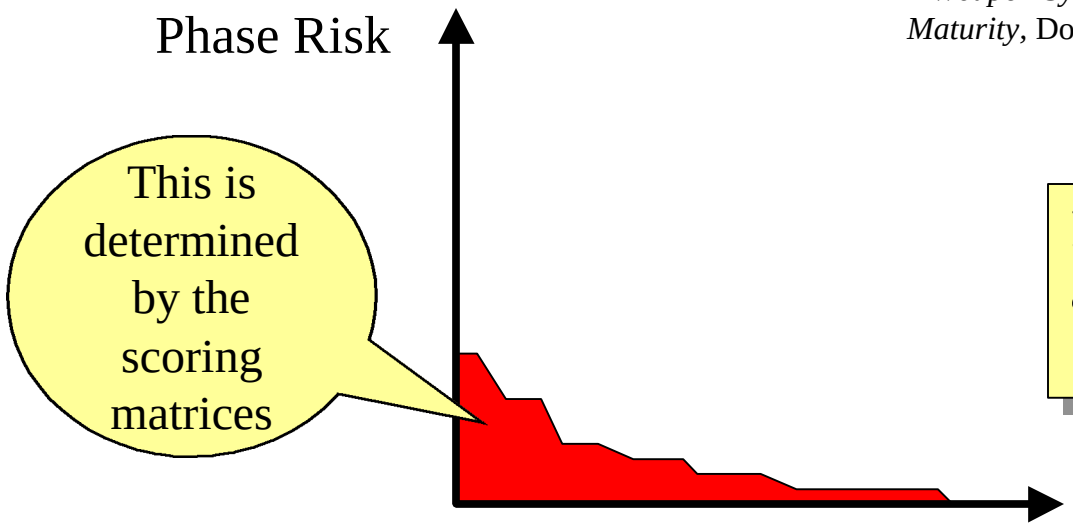
## What happens to risk as we proceed through time?

# Progression of Phase Cost and Risk



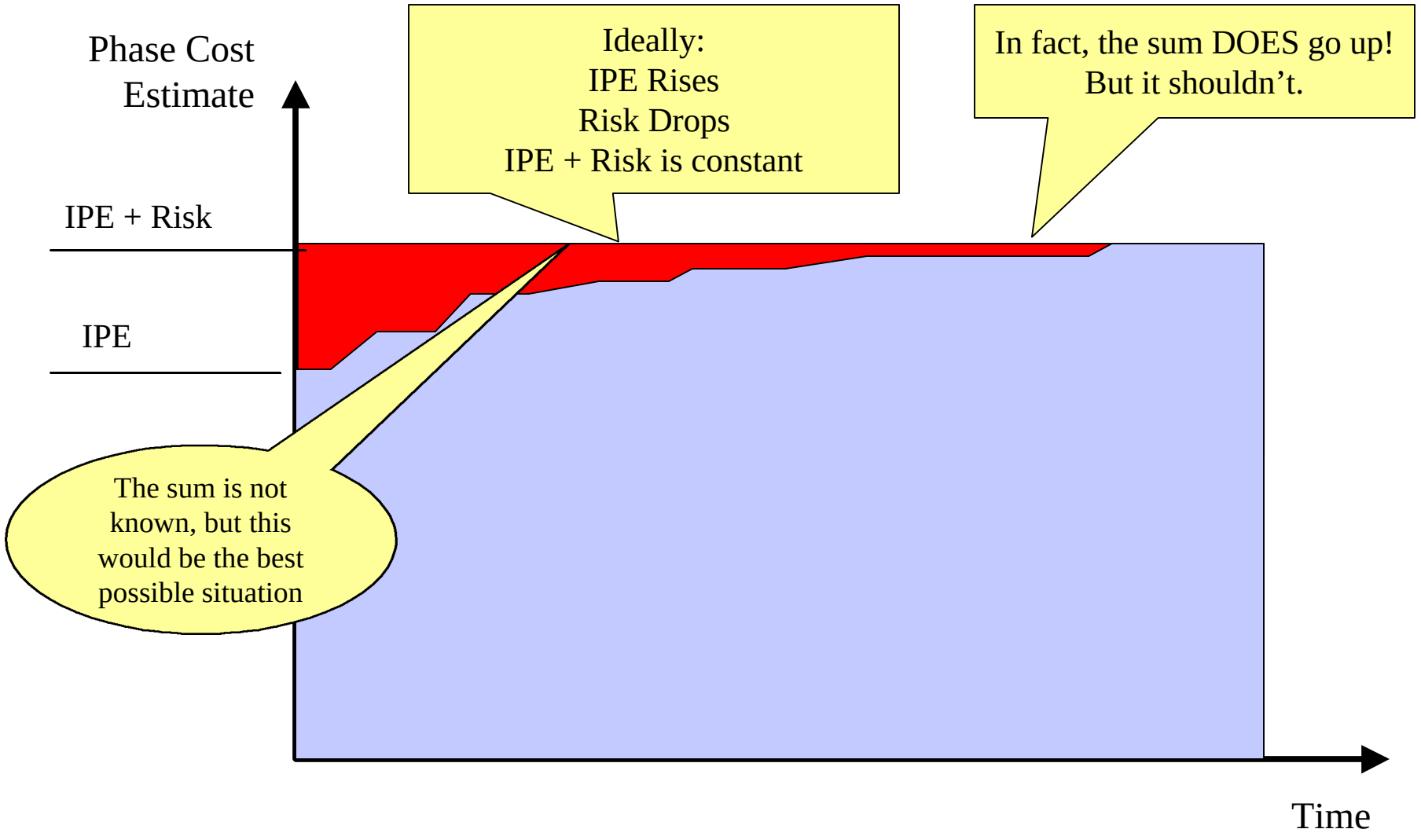

**Phase cost estimates rise as risk is 'realized'**

*1 Weapon System Cost Growth As a Function of Maturity*, DoDCAS 1996, K. J. Allison, R. L. Coleman

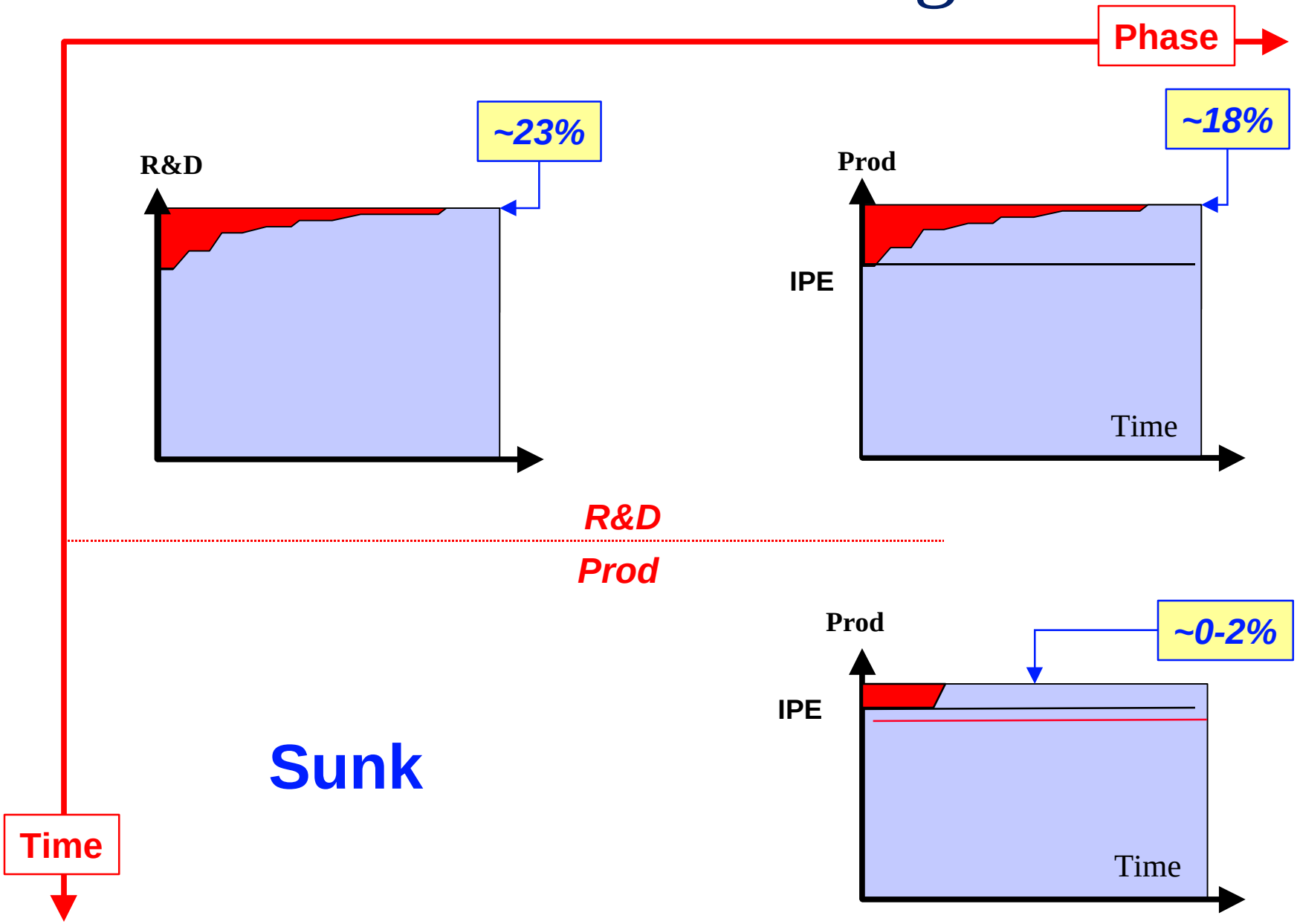



**Phase risk estimates fall as the scores assigned to items drop over time**

# Progression of Cost + Risk



# Combined Image



# The BMDO Risk Methodology

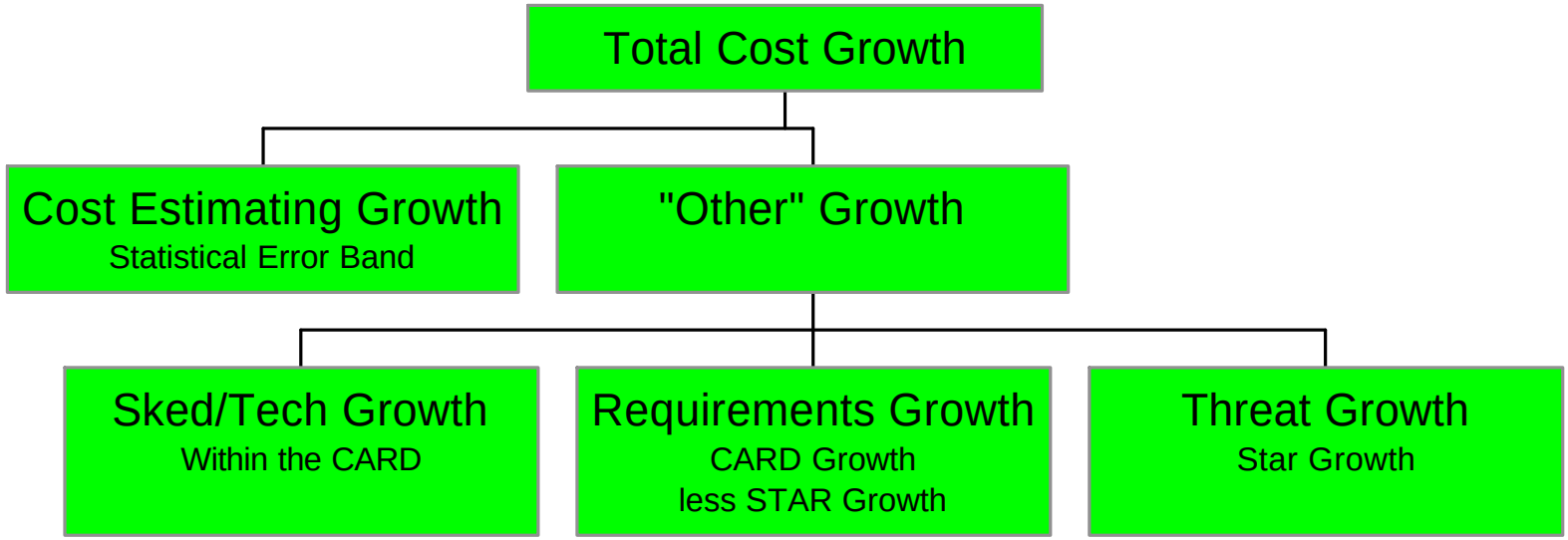
# History of BMDO Cost Risk Model

- **Original methodology published in May 1990.**
  - **–Three revisions have since been published, the latest version (Rev. 3) in June 1998.**
- **Extensively briefed to and well received by members of the cost community at DoDCAS, SCEA/ISPA, and the BMDO Cost Risk Review Group**
  - **–Awards received: Best Paper (DoDCAS 1993), Best Paper by a Contractor (DoDCAS 1995), Outstanding Contributed Paper (DoDCAS 1998)**
- **Submitted to academic scrutiny by numerous organizations including IDA, Mitre, ALMC, and OSD CAIG**
- **Nine years of continuous internal and external critiques have resulted in a model that is the state of the art**

# Definitions (BMDO)

- **Cost Growth = Cost Estimating Growth + Sked/Tech Growth + Requirements Growth + Threat Growth**
- **Cost Risk = Cost Estimating Risk + Sked/Technical Risk + Requirements Risk + Threat Risk**
  - **Cost Estimating Risk: Risk due to cost estimating errors, and the statistical uncertainty in the estimate**
  - **Schedule/Technical Risk: Risk due to inability to conquer problems posed by the intended design in the current CARD**
  - **Requirements Risk: Risk due to as-yet-unseen design shift from the current CARD arising due to CARD shortfalls**
    - **Due to the inability of the intended design to perform the (unchanged) intended mission**
    - **We didn't understand the solution**
  - **Threat Risk: Risk due to as-yet-unrevealed threat shift from the current STAR**
    - **We didn't understand the problem**

# Cost Growth Categories
## *As Contained in SARs*



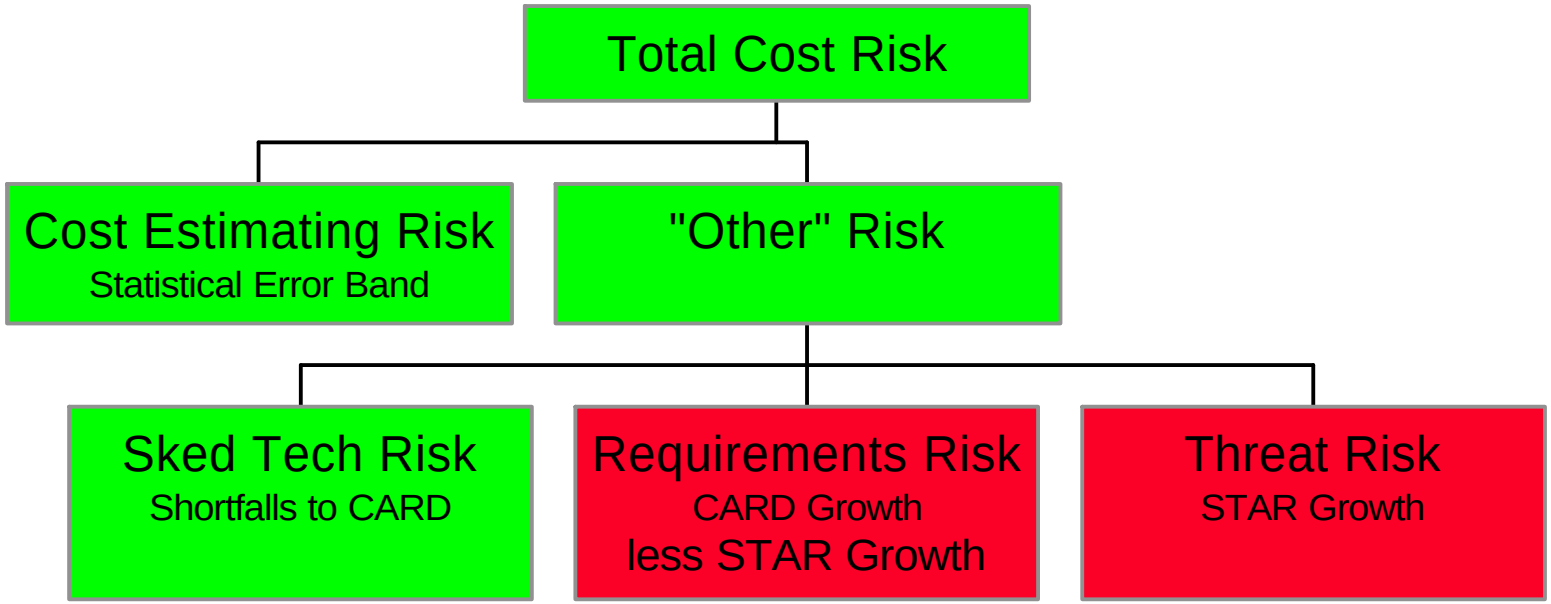

Included

Excluded

**Because history has all of this, and we didn't remove it, it is in our factors**

# Risk Categories

## *As Estimated in the BMDO Model*




Explicit

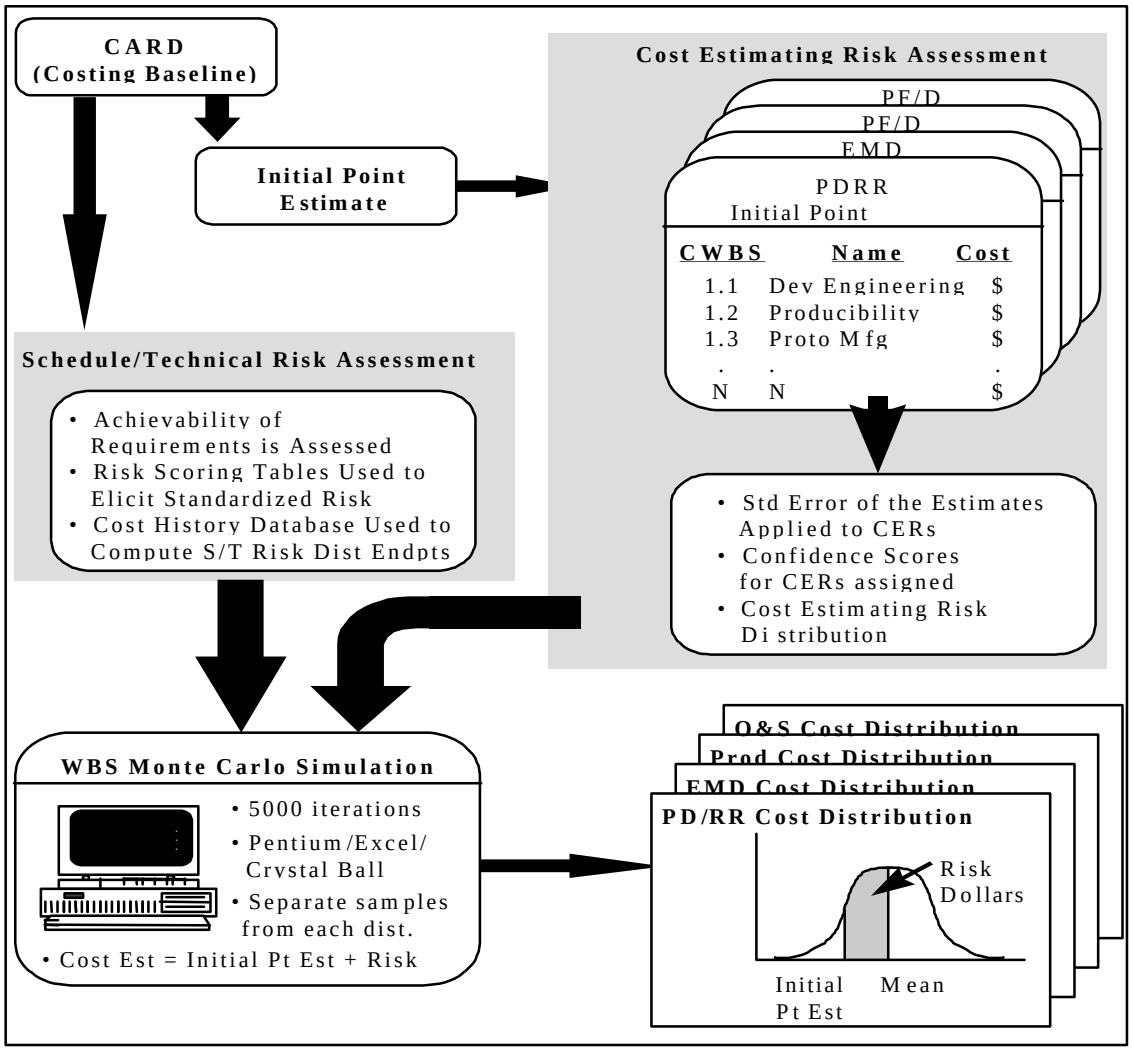
Implicit

**Because it is in our factors, it is in our risk**

# BMDO Cost Risk Assessment Approach

- **Develop a cost estimating risk distribution for each CWBS element**
- **Develop a schedule/technical risk distribution for each WBS entry for:**
  - **Hardware**
  - **Software**
  - **IA&T**
  - **Note that "Below-the-line" WBS elements get risk from Above-the-line WBS elements**
- **Combine these risk distributions and the point estimate using a Monte Carlo simulation**
  - **Produces a distribution including risk for each phase of a cost estimate**

# Cost Risk Assessment Approach



# Schedule/Technical Risk Assessment

- **Technical risk is decomposed into categories**
- **Hardware items have six categories**
  - **Technology Advancement, Engineering Development, Reliability, Producibility, Alternative item and Schedule**
- **Software items have seven categories**
  - **Technology Approach, Design Engineering, Coding, Integrated Software, Testing, Alternatives, and Schedule**
- **IA&T items have nine categories**
  - **Technology, Engineering Development (Hardware and Software), Interface Complexity, Subsystem Integration, Major Component Production, Schedule (Hardware and Software) and Reliability**

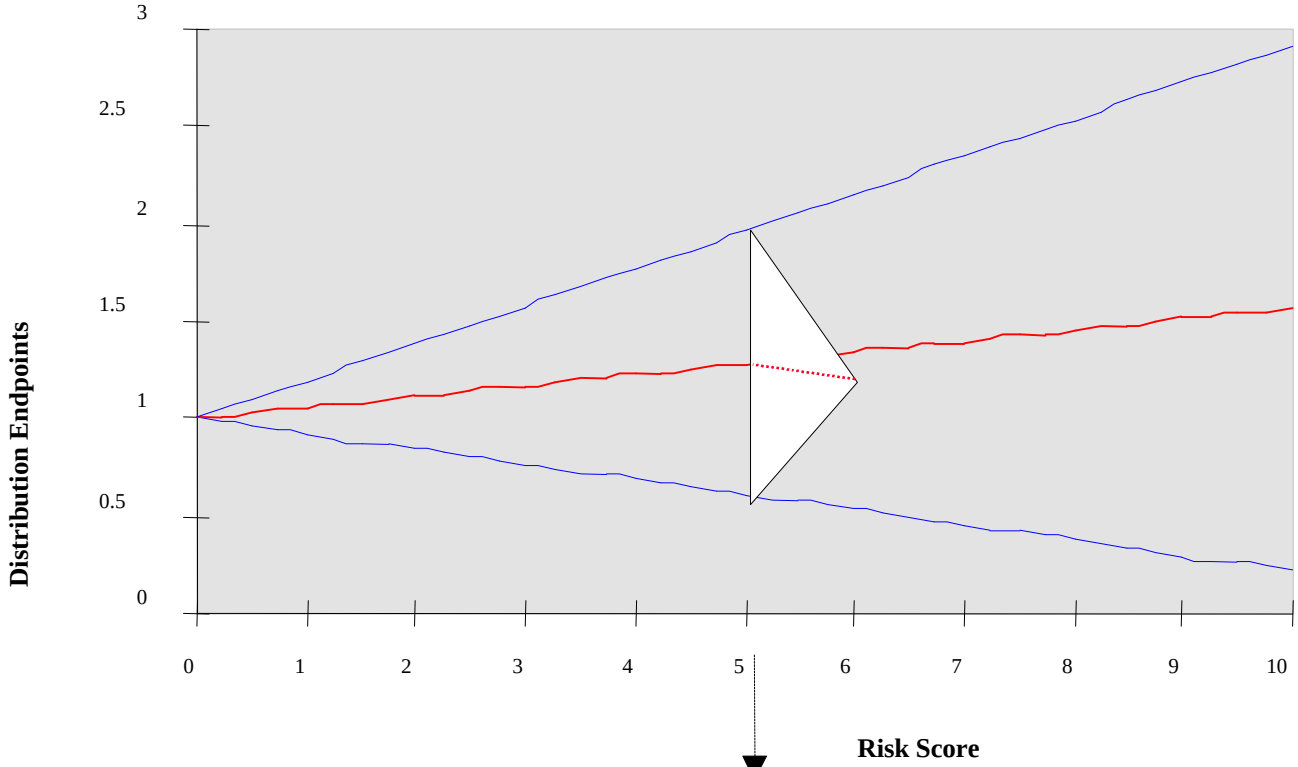
# Calculating Schedule/Technical Risk Endpoints

- **Technical experts score each of the categories from 0 (no risk) to 10 (high risk)**
- **Each category is weighted depending on the relevancy of the category**
- **Weighted average risk scores are mapped to a cost growth distribution**
  - **This distribution is based on a database of cost growth factors of major weapon systems collected from SARs. These programs range from those which experienced tremendous cost growth due to technical problems to those which where well managed and under budget.**

# Hardware Risk Scoring Matrix

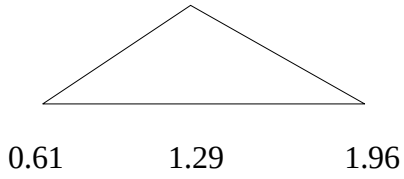
| Risk Categories | | Risk Scores (0=Low, 5=Medium, 10=High) | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 1-2 | 3-5 | 6-8 | 9-10 |
| 1 | Technology Advancement | Completed (State of the Art) | Minimum Advancement Required | Modest Advancement Required | Significant Advancement Required | New Technology |
| 2 | Engineering Development | Completed (Fully Tested) | Prototype | HW/SW Development | Detailed Design | Concept Defined |
| 3 | Reliability | Historically High for Same Item | Historically High on Similar Items | Known Modest Problems | Known Serious Problems | Unknown |
| 4 | Producibility | Production & Yield Shown on Same Item | Production & Yield Shown on Similar Items | Production & Yield Feasible | Production Feasible & Yield Problems | No Known Production Experience |
| 5 | Alternate Item | Exists or Availability on Other Items Not Important | Exists or Availability of Other Items Somewhat Important | Potential Alternative Under Development | Potential Alternative in Design | Alternative Does Not Exist & is Required |
| 6 | Schedule | Easily Achievable | Achievable | Somewhat Challenging | Challenging | Very Challenging |

# Sked./Tech Score Mapping




Example

For Risk Score = 5:

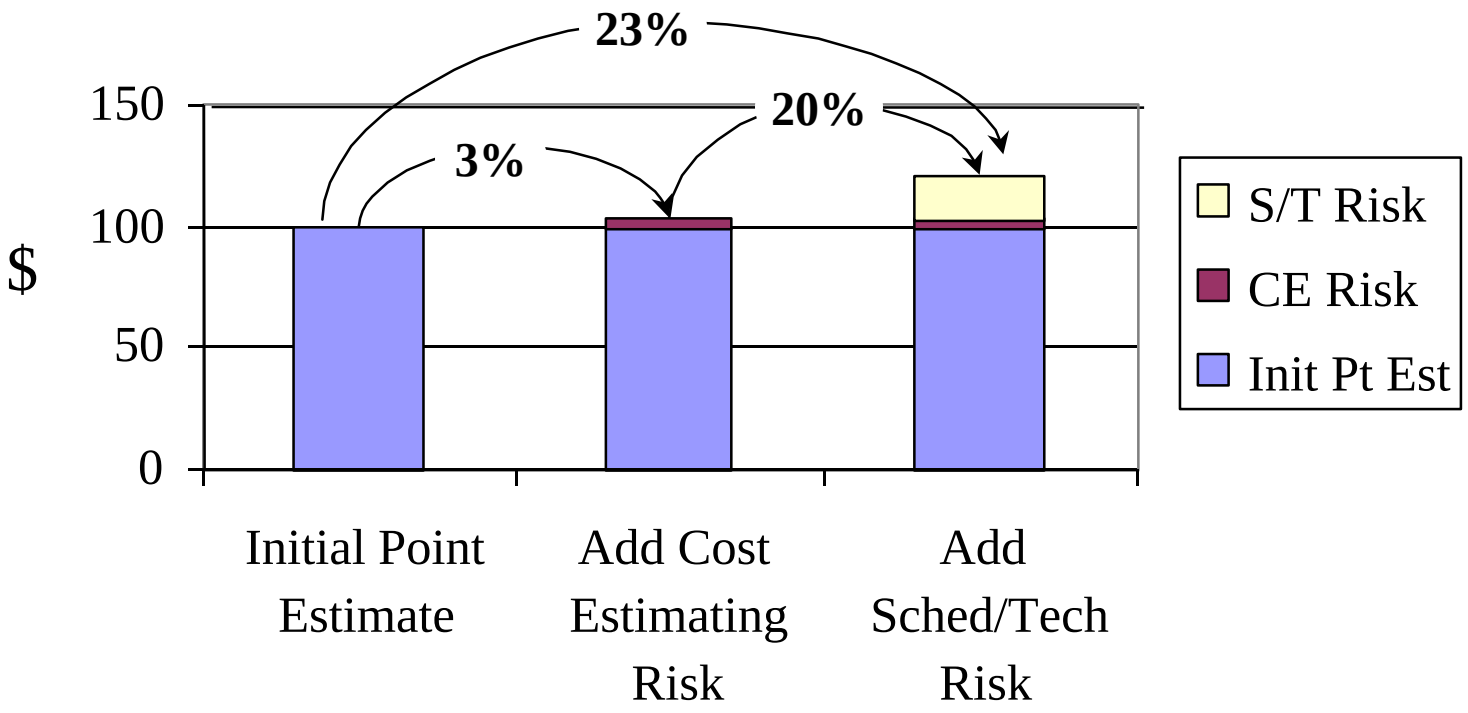



Mean = 1.29

# Cost Estimating Risk Assessment

- **Consists of the standard error associated with the costing methodologies**
- **Cost analysts' assessment of:**
  - **Applicability of the step-up/step-down functions**
  - **Uncertainty surrounding the learning curves**
  - **Currency and relevancy of the database on which the CERs rely**

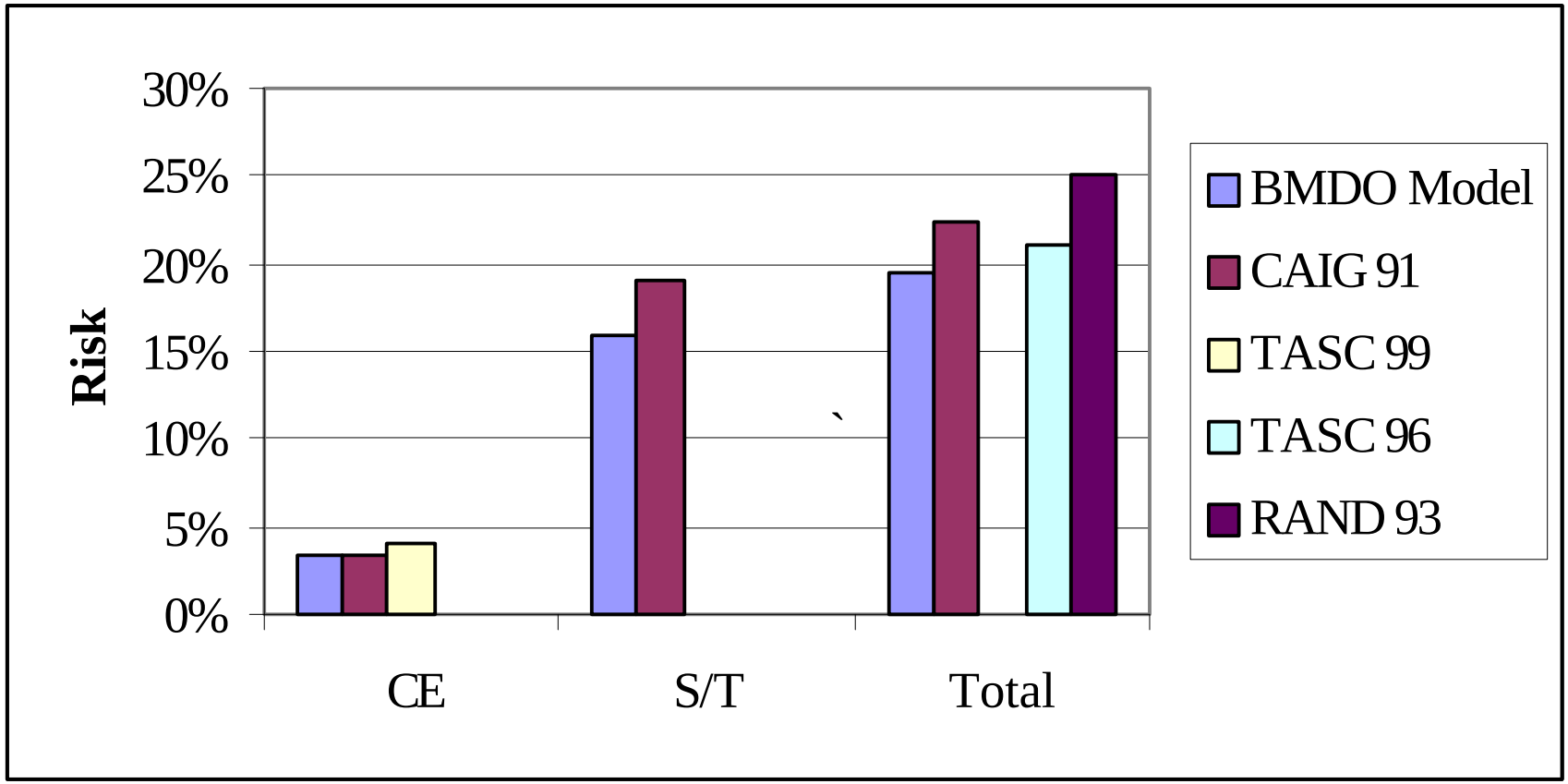
# Example Cost Estimate with Risk



# How does the BMDO Model Compare to History?

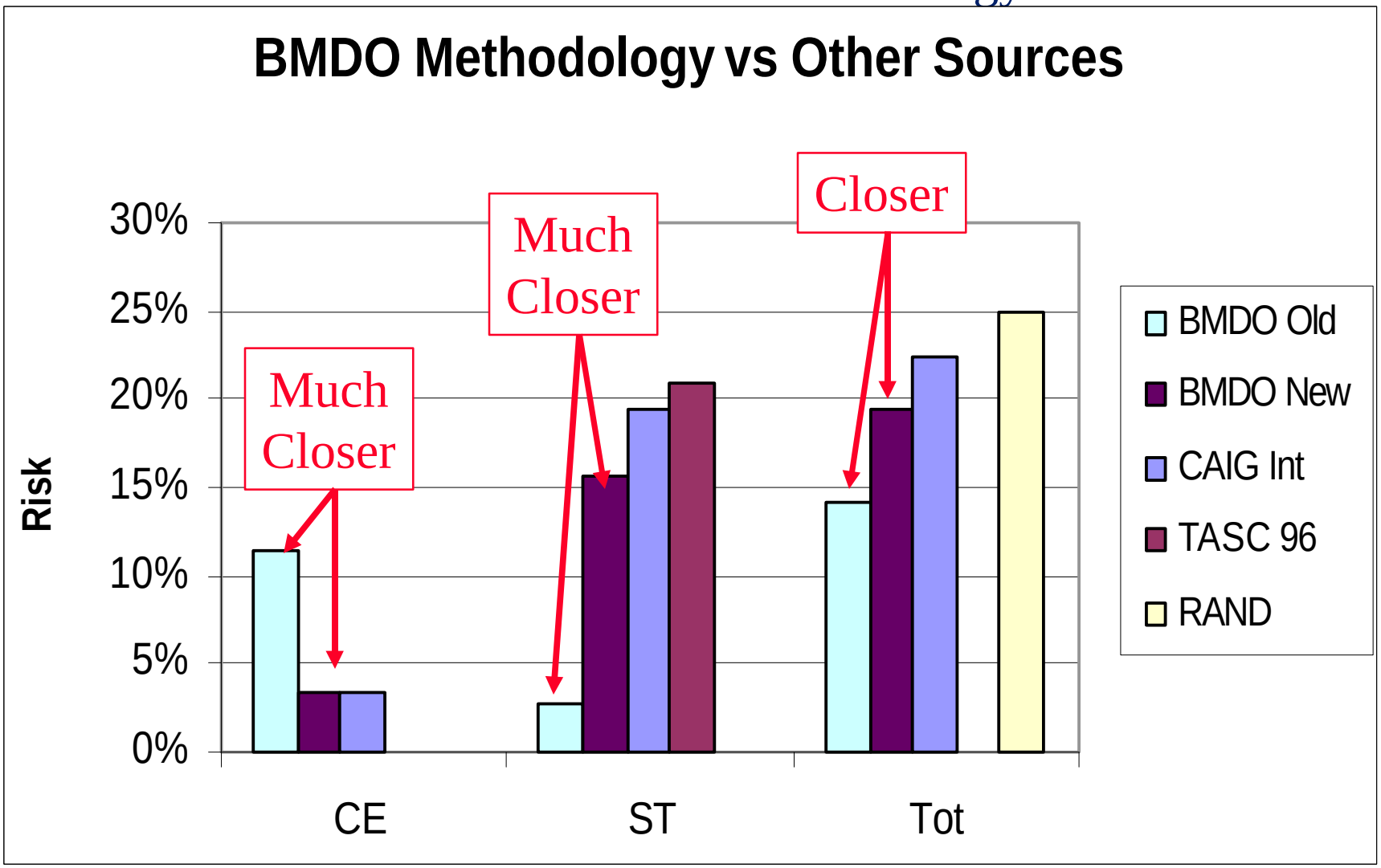
# Comparison of Mean Risk Results

## BMDO Methodology vs Other Sources

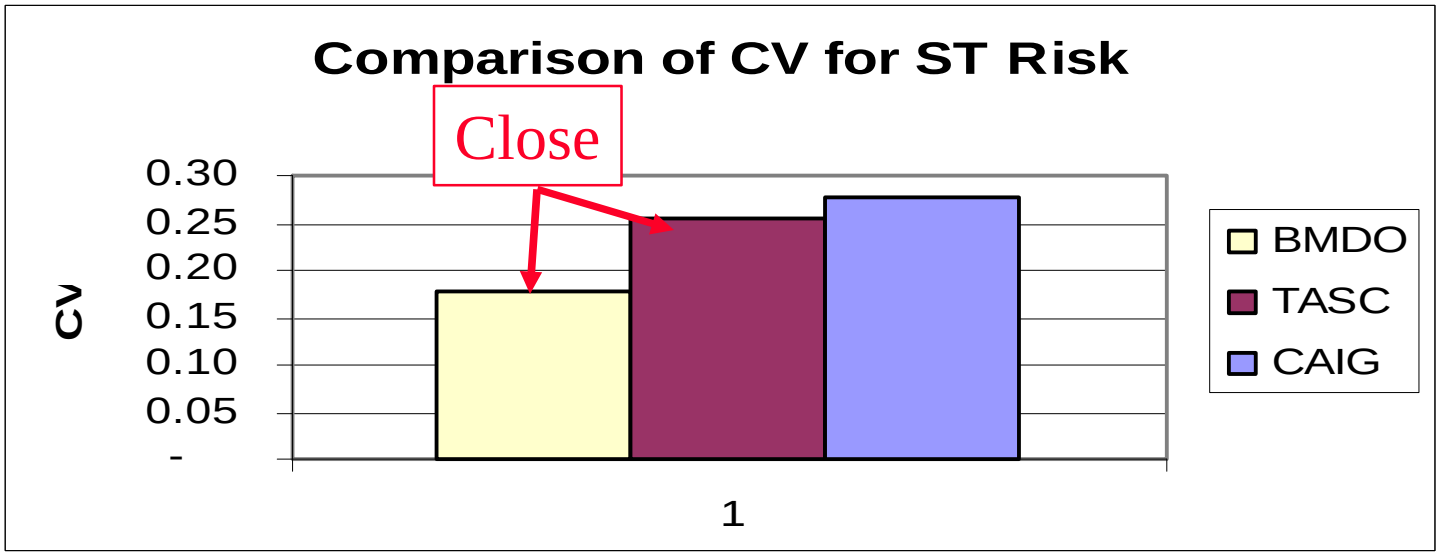


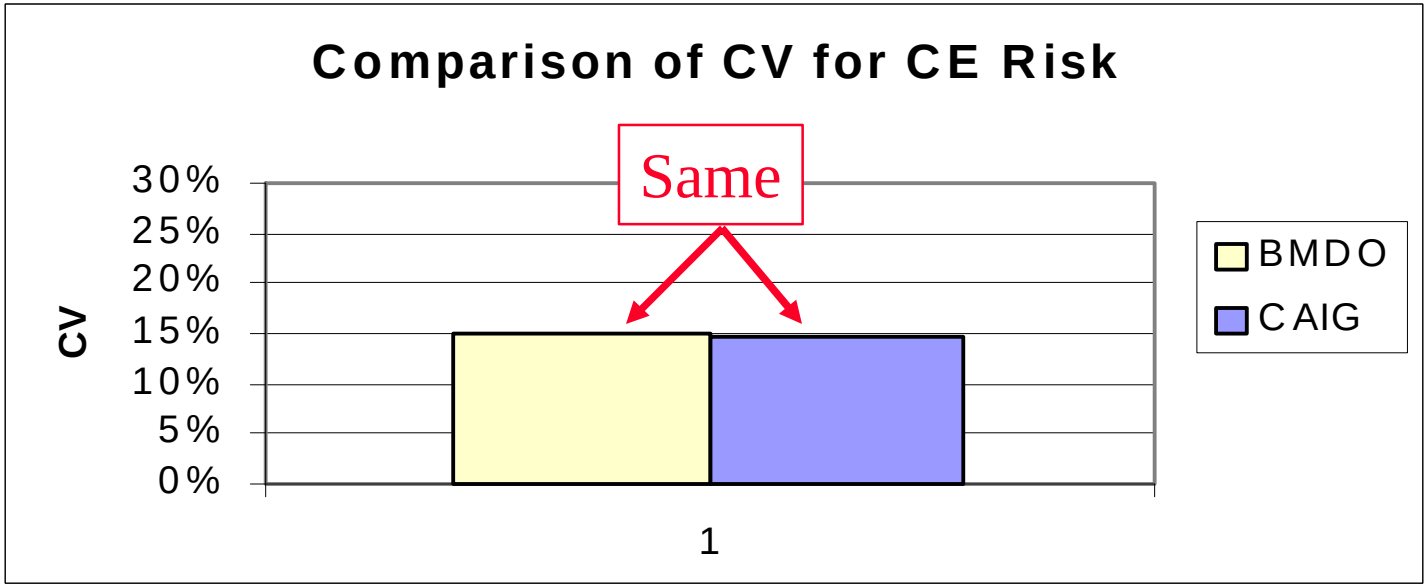
# Comparison of Mean S/T Risk Results

## BMDO's Revised Methodology



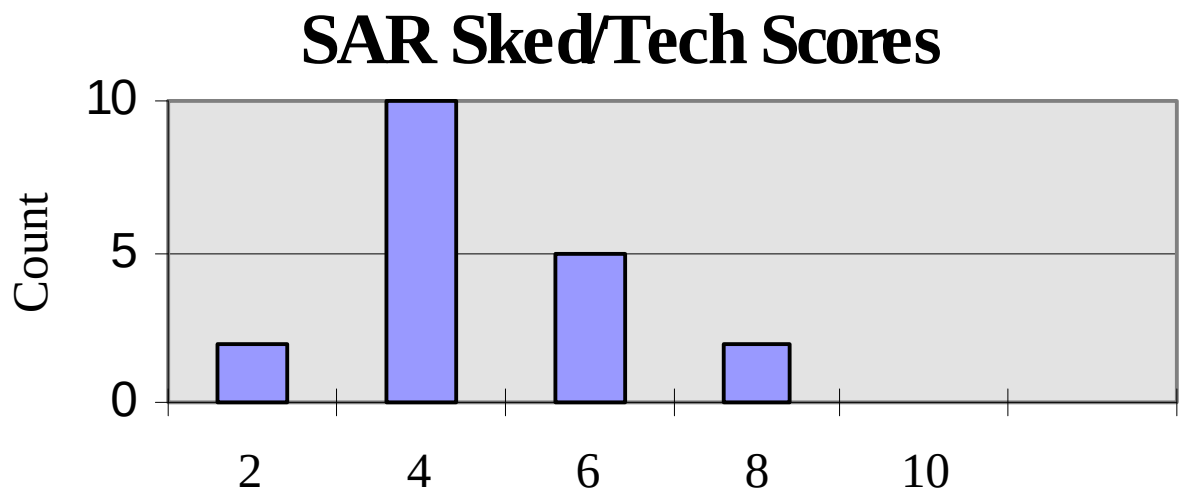
# Comparison of CV for S/T Risk Results

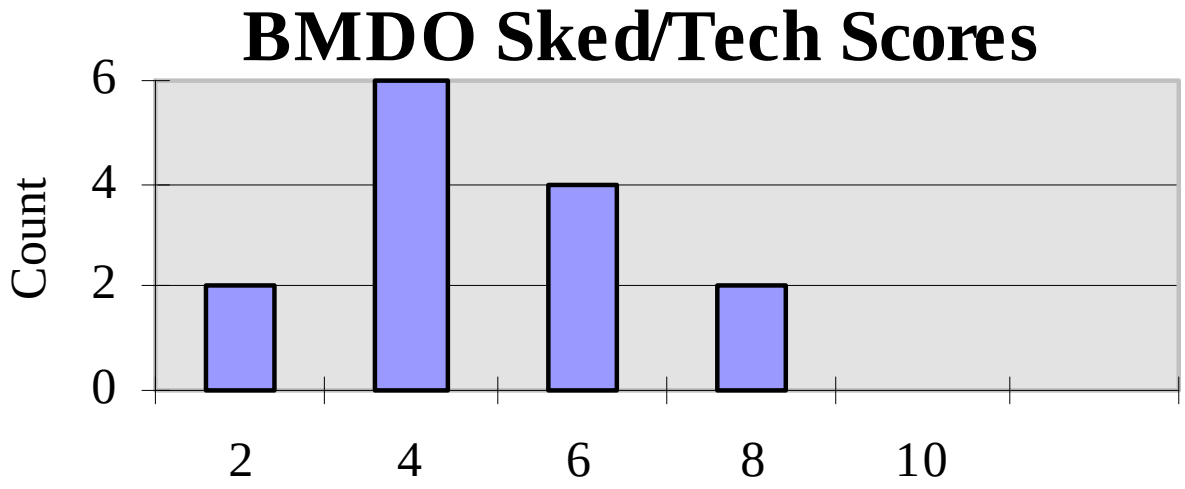


# Historical SARs vs. BMDO Risk Scores

Observations
- Both skewed right
- Very similar pattern
- BMDO somewhat more skewed




**Conclusion: BMDO's risk scores are comparable to those of the data base**

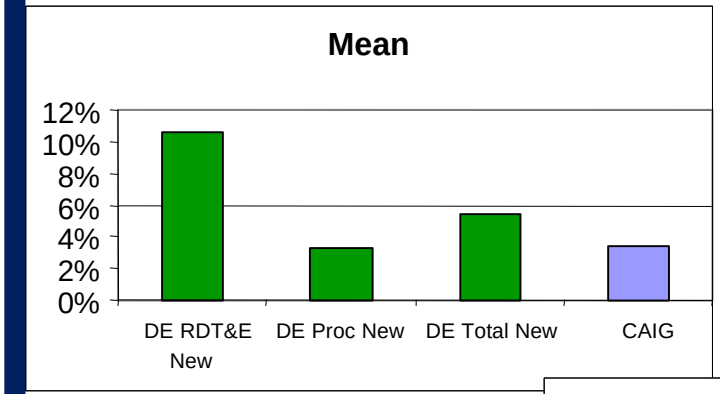
# Cost Estimating Risk

| Strict CE | PE *RDT&E* | DE *RDT&E* | DE *Proc* | Prod *Proc* |
|---|---|---|---|---|
| **Mean** | 7.0% | 10.7% | 3.3% | 3.0% |
| **Std Dev** | 15.5% | 15.3% | 24.5% | 6.3% |
| **CV** | 2.2 | 1.4 | 7.4 | 2.1 |
| **Skewness** | 0.358 | 0.987 | 0.560 | 0.794 |
| **Kolmogorov-Smirnov** | 0.124 *PASS* | 0.154 *PASS* | 0.109 *PASS* | 0.231 *FAIL* |

**Cost Estimating Risk is Normally Distributed**

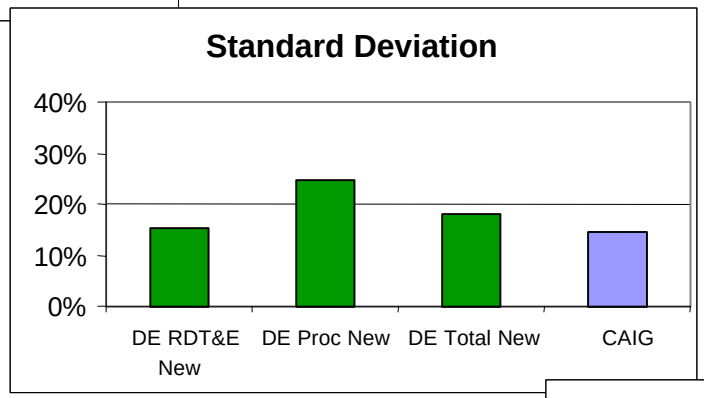
**By phase: DE--RDT&E and DE--Procurement were not correlated.**

# Cost Estimating Risk - BMDO Database

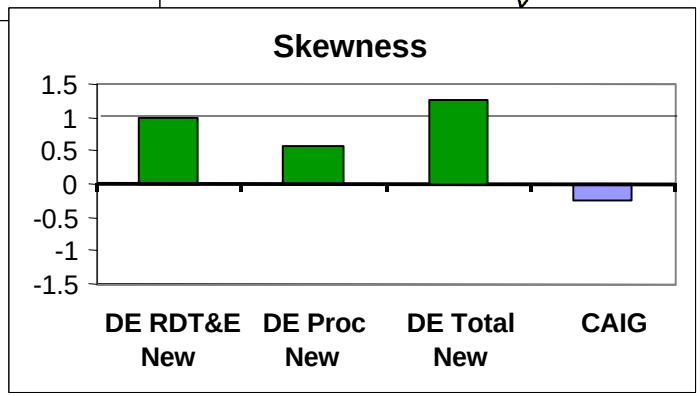



**Cost Estimating Risk appears different by phase, but tests show no statistical difference**
**It is similar to CAIG data**

**All the standard deviations are comparable.**




**The skewness picture is quite different.**



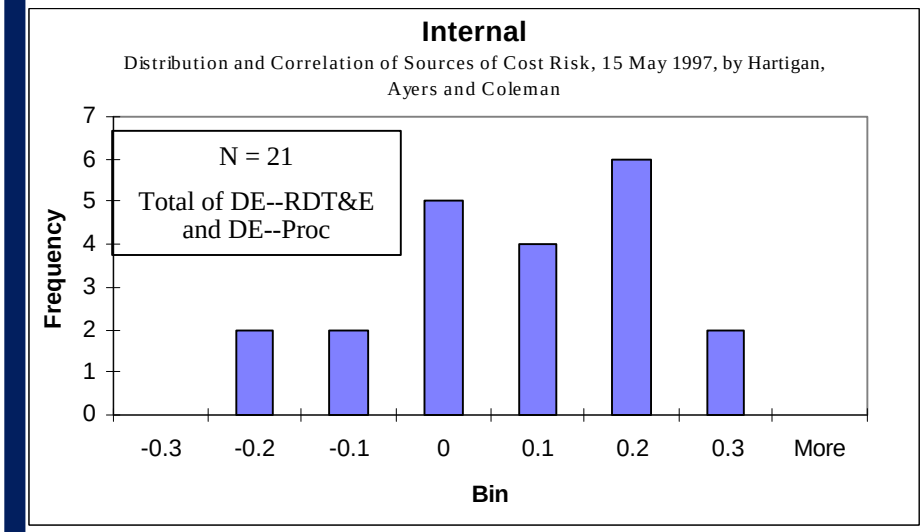

**Conclusion:**

**First and second moments are similar to other data**

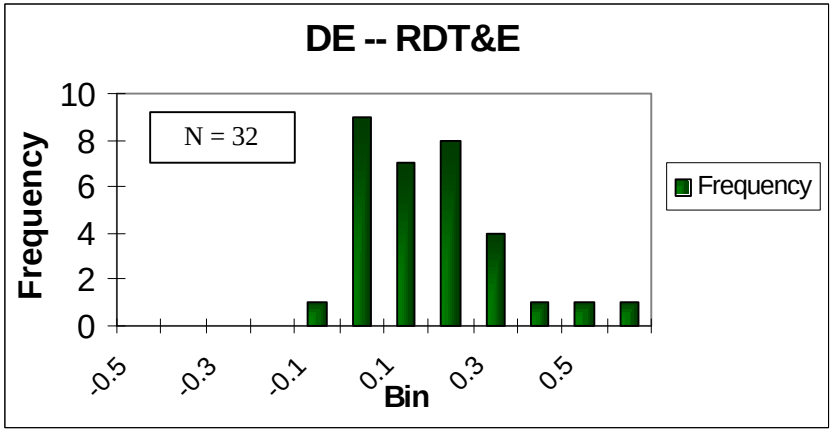
# Comparison of Distribution

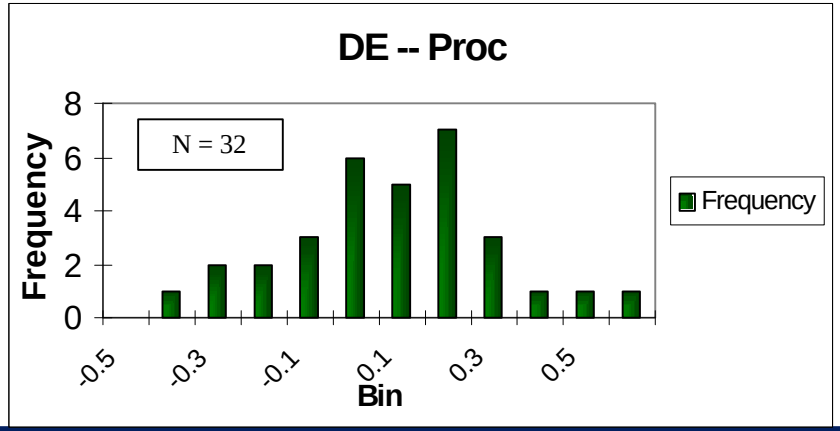
## CE Risk - BMDO Database

**CAIG Data - Total Acquisition**




**New Data**




**Conclusion:**

**Data distributions are similar**

# Conclusion

- Given all the issues and options, the BMDO methodology combines the most practical methods with rigorous research on historical data to produce a state-of-the-art model
- The model produces results that compare very closely with history

# Risk Bibliography


- *An Overview of Correlation and Functional Dependencies in Cost Risk and Uncertainty Analysis,* DoDCAS 1994**,** R. L. Coleman, S. S. Gupta
- *Quantification of Total Cost Risk for Ground Communications/Electronics Systems,* October 1995, K. J. Allison, J. E. Sunderlin, R. L. Coleman
- *Weapon System Cost Growth As a Function of Maturity*, DoDCAS 1996, **K. J. Allison, R. L. Coleman**
- *Cost Response Curves - Their generation, their use in IPTs, Analyses of Alternatives, and Budgets,* DoDCAS 1996**,** K. J. Allison, K. E. Crum, R. L. Coleman, R. G. Klion
- ***Distribution and Correlation of Sources of Cost Variance***, May 1997, G. E. Hartigan, J. R. Summerville, R. L. Coleman
- *Cost Risk Estimates Incorporating Functional Correlation, Acquisition Phase Relationships, and Realized Risk*, SCEA National Conference 1997, R. L. Coleman, S. S. Gupta, J. R. Summerville, G. E. Hartigan
- *Cost Risk Analysis of the Ballistic Missile Defense (BMD) System, An Overview of New Initiatives Included in the BMDO Risk Methodology*, DoDCAS 1998 Outstanding Contributed Paper, and SCEA/ISPA International Conference 1998, R. L. Coleman, J. R. Summerville, D. M. Snead, S. S. Gupta, G. E. Hartigan, N. L. St. Louis
- *Risk Analysis of a Major Government Information Production System, Expert-Opinion-Based Software Cost Risk Analysis Methodology*, DoDCAS 1998 Outstanding Contributed Paper, and SCEA/ISPA International Conference 1998 Overall Best Paper Award, N. L. St. Louis, F. K. Blackburn, R. L. Coleman
- *Analysis and Implementation of Cost Estimating Risk in the Ballistic Missile Defense Organization (BMDO) Risk Model, A Study of Distribution,* Joint ISPA/SCEA International Conference 1999, J. R. Summerville, H. F. Chelson, R. L. Coleman, D. M. Snead
- *Risk in Cost Estimating*, 1999 Integrated Program Management Conference**,** R. L. Coleman, J. R. Summerville, M. R. DuBois
- *Risk in Cost Estimating General Introduction & The BMDO Approach*, 33rd DoDCAS 2000, R. L. Coleman, J. R. Summerville, M. DuBois, B. Myers

# Synopsis of Recent Risk Research Papers

•*Analysis and Implementation of Cost Estimating Risk in the Ballistic Missile Defense Organization (BMDO) Risk Model, A Study of Distribution*, Joint ISPA/SCEA International Conference 1999, H. F. Chelson, J. R. Summerville, R. L. Coleman, D. M. Snead

- Purpose: To review the Cost Estimating(CE) risk component of BMDO's Cost Risk Methodology and to gain insight into CE risk
- Approach: New SAR databases were created and pure CE error was analyzed
- Conclusions:

  •Weighted average yield 4.1% CE risk

  (current CE risk 3.4%)

  •This study was instrumental in giving a very good understanding of CE risk

# Synopsis of Recent Risk Research Papers

•*Risk Analysis of a Major Government Information Production System*, *Expert-Opinion-Based Software Cost Risk Analysis Methodology*, DoDCAS 1998 Outstanding Contributed Paper, and Best Paper Overall, SCEA/ISPA International Conference 1998, N. L. St. Louis, F. K. Blackburn, R. L. Coleman

- Purpose: Describe an approach to determining Cost Risk when historical databases are not available
- Approach: Questionnaires are developed, Expert opinion is solicited, inputs are conflated, and Monte Carlo simulations are run.
- Conclusion: Cost risk of 49%. Mitigationchoices identified to reduce risk to 29%.

# Synopsis of Recent Risk Research Papers

•*Cost Risk Analysis of the Ballistic Missile Defense (BMD) System, An Overview of New Initiatives Included in the BMDO Risk Methodology*, DoDCAS 1998 Outstanding Contributed Paper, and SCEA/ISPA International Conference 1998, R. L. Coleman, J. R. Summerville, D. M. Snead, S. S. Gupta, G. E. Hartigan, N. L. St. Louis

- Purpose: An overview of new initiatives included in the BMDO Risk Methodology
- Approach: The BMDO model was improved by implementing functional correlation, an improved schedule/technical risk score to risk factor mapping, reduced cost estimating risk (symmetric normal), and phase to phase functional correlation
- Conclusion: New cost risk of 17-22%. Cost risk prior to the new implementation was 12-20%. Proportion of Sched/Tech risk increased and Cost Estimating risk decreased.

# Synopsis of Recent Risk Research Papers

•*Cost Risk Estimates Incorporating Functional Correlation, Acquisition Phase Relationships, and Realized Risk*, SCEA National Conference 1997, R. L. Coleman, S. S. Gupta, J. R. Summerville, G. E. Hartigan

- Purpose: To examine correlation between phases in cost estimation
- Approach: Incorporate Phase-to-Phase Functional Correlation (PTPFC) in the BMDO Risk Model and compare results to SAR data analysis
- Implication: Cost Growth in EMD and Production is correlated, and is caused by a *single* driving effect: hardware cost
- Conclusion: Functional correlation can be used to achieve correlation *between* and *within* phases using hardware as the main driver

# Important Papers on SARs

- *An Analysis of Weapon System Cost Growth*, 1993, J. Drezner et al (RAND)
  - –Study gains insight into both the magnitude of weapon system cost growth and factors that affect the cost growth phenomena
  - –The definitive study of SARs
- *Pitfalls in Calculating Cost Growth from Selected Acquisition Reports (SARs)*, 1992, P. Hough, RAND
  - –Paper examines weaknesses in SAR databases and how they influence calculations of program cost growth
    - •e.g. Failure to carry a consistent baseline cost estimate, Inconsistent interpretation of preparation guidelines, Reporting of effects of cost changes rather than their root causes, etc.
  - –Conclusion: "Even though SAR data have a number of limitations when used for purposes of calculating cost growth, they nevertheless are suitable for identifying broad-based trends and temporal patterns across a range of programs."

# A Brief History of Key Risk Ideas[1,2]

1654 - Pascal creates probability while solving "The Problem of Points" for the Chevalier de Mere.

1657 - Pascal's work published by Christiaan Huygens as *De Ratiociniis in Ludo Alae*

The Problem of Points Question for Pascal:

– Two people, A and B, are playing a fair game of balla (a dice game.) They agree to continue until one has won six rounds. The game actually stops when A has won five and B three. How should the stakes be divided?

1 *Discovering the Odds* by J. W. Stewart - Smithsonian, Jun 99
2 *Against the Gods* by Peter L. Bernstein

# A Brief History of Key Risk Ideas cont.

1661 - Graunt pioneers statistics in *Natural and Political Observations made upon the Bills of Mortality*.

– Showed that data, through statistical inference, could point toward causality, while studying why most people worry about dying from causes that actually are not very likely to kill them.

1730 - De Moivre discovers and plots the Normal Distribution 1809 - LaPlace develops the Central Limit Theorem

# A Brief History of Key Risk Ideas cont.

## 1812 - Laplace publishes *Theorie Analytique des Probabilities*

- DeMoivre became intrigued with the well known observation that a range of variations exists in almost any set of similar phenomena or populations. Concluding that on a graph the distribution of these variations often follows a particular curve, which looks something like a bell.

# A Brief History of Key Risk Ideas cont.

1875 - Galton discovers “Regression to the Mean” in an experiment with sweet peas. He pioneers the idea of correlation.

- Regression to the mean says that above average parents will tend to have offspring that are closer to the mean (“worse”) than they were - likewise, below average parents will tend to have “better” offspring.

# A Brief History of Key Risk Ideas cont.

Obituary for Arthur Rudolph, the scientist who developed the Saturn 5 rocket that launched the first Apollo mission to the moon put it this way: "You want a valve that doesn't leak and you try everything possible to develop one. But the real world provides you with a leaky valve. You have to determine how much leaking you can tolerate."

The role of the cost estimator is to determine the cost of the valve - historically, to push the point, the cost estimator costs out the leaky version..

The role of the cost risk analyst is to determine the cost of improving the leak from the first, unacceptable design to the final design.

# Backup

# Software Risk Scoring Matrix

| Risk Categories | Risk Scores (0=Low, 5=Medium, 10=High) | | | | |
|---|---|---|---|---|---|
| | 0 | 1-2 | 3-5 | 6-8 | 9-10 |
| 1 Technology Approach | Proven Conventional Analytic Approach; Standard Methods | Undemonstrated Conventional Approach, Standard Methods | Emerging Approaches, New Applications | Unconventional Approach, Concept Under Development | Unconventional Approach, Unproven |
| 2 Design Engineering | Design Completed & Validated | Specifications Defined & Validated | Specifications Defined | Requirements Defined | Requirements Partially Defined |
| 3 Coding | Fully Integrated Code Available & Validated | Fully Integrated Code Available | Modules Integrated | Modules Exist but are Not Integrated | Wholly New Design; No Modules Exist |
| 4 Integrated Software | Thousands of Instructions | Tens of Thousands of Instructions | Hundreds of Thousands of Instructions | Millions of Instructions | Tens of Millions of Instructions |
| 5 Testing | Tested with System | Tested by Simulation | Structured Walk-Throughs Conducted | Modules Tested (Not as a System) | Untested Modules |
| 6 Alternatives | Alternatives Exist; Alternative Design is Not Important | Alternatives Exist; Design is Somewhat Important | Potential Alternatives are Under Development | Potential Alternatives are Under Consideration | Alternative Does Not Exist but is Required |
| 7 Schedule & Management | Relaxed Schedule, Serial Activities, High Review Cycle Frequence; Early First Review | Modest Schedule, Few Concurrent Activities; Reasonable Review Cycle | Modest Schedule, Many Concurrent Activities; Occasional Reviews Scheduled Late First Review | Fast Track but on Schedule; Numerous Concurrent Activities | Fast Track with Missed Milestones; Review Only at Demonstrations; No Periodic Reviews |

# IA&T Risk Scoring Matrix

| Risk Categories | Risk Scores (0=Low, 5=Medium, 10=High) | | | | |
|---|---|---|---|---|---|
| | 0 | 1-2 | 3-5 | 6-8 | 9-10 |
| 1 Technology (Highest Level in System) | Off the Shelf Old Technology | Off the Shelf State of the Art Technology | Modest Advancement Required | Significant Advancement Required | New Technology Development |
| 2 Engineering Development (Hardware) | System Complete Fully Tested | System Incomplete & Untested | Hardware Development | Detailed Design Completed | Preliminary Design Completed |
| 3 Engineering Development (Software) | Software Complete Fully Tested | Beta Version Tested | Software Development | HW/SW Interfaces Defined | Preliminary Architecture Defined |
| 4 Interfaces Complexity | Standards Based; Few Simple Interfaces | Standards Based; Many Simple Interfaces | Limited Standards; Many Interfaces | Limited Standards; More Complex Interfaces | No Standards; Many Complex Interfaces |
| 5 Subsystem Integration | All Subsystems Integrated and Tested | Subsystems Integrated; Not Tested | OTS/MOTS Subsystems & Interfaces Defined | New Development Subsystems & Interfaces Defined | Subsystem Requirements Defined |
| 6 Major Component Production | Production and Yield Demonstrated on Same System | Production and Yield Demonstrated on Similar System | Production Plan Established; Yield Feasible | Production Feasible; Yield Potential Unknown | No Known Production Experience |
| 7 Schedule (Hardware) | Achievable; No Critical Paths; Adequate Resources | Achievable; Few Critical Paths; Adequate Resources | Challenging; Few Critical Paths; Limited Resources | Challenging; Many Critical Paths; Limited Resources | Very Challenging; Many Critical Paths; Resources Shortfall |
| 8 Schedule (Software) | Not Time Critical | Critical Path; Below Average SLOC per Day | Critical Path; Average SLOC per Day | Critical Path; Above Average SLOC per Day; Resources Available | Very Challenging; Many Critical Paths; Resources Shortfall |
| 9 Reliability | High Reliability Demonstrated; Predicted High | High Reliability on Similar Systems; Predicted High | Known Modest Problems; Predicted High | Known Serious Problems; Predicted High | Unknown/Serious Problems; Predicted Low |

# SE&I Risk Scoring Matrix

| Risk Categories | Risk Scores (0=Low, 5=Medium, 10=High) | | | | |
|---|---|---|---|---|---|
| | 0 | 1-2 | 3-5 | 6-8 | 9-10 |
| 1 Technology Advancement | No New Tech or COTS | Minimum Advancement | Modest Advancement | Significant Advance | New Technology |
| 2 Engineering Development | Completed or COTS | Prototype | HW/SW Development | Detailed Design | Concept Defined |
| 3 Coordination Required | None, Single Source | Minimum Std I/F | Modest MIS Connection | Significant, Many Sources | New Team Multiple Source |
| 4 Analytical Toolset | Fully Automated COTS | Automated Minimum Customization | Custom to Integrate | Custom Development | Manual Analysis |
| 5 Interface Control | Fully Standard Interfaces | Specifications Frozen | "Plug & Play" Interfaces | Interface SW to Develop | Interface to Enhance Performance |
| 6 Schedule | Easy | Achievable | Some Challenge | Challenging Risky Path | Difficult Critical Path |

# ST&E Risk Scoring Matrix

| Risk Categories | Risk Scores (0=Low, 5=Medium, 10=High) | | | | |
|---|---|---|---|---|---|
| | 0 | 1-2 | 3-5 | 6-8 | 9-10 |
| 1 Test Hardware Tech Instrumentation Tech | Existing TE Suite | Assemble Proven Tech | Special Instrumentation | Special Instr & Calibration | New Eqpt & Instruments |
| 2 Simulation Technology | All Test No Simulation | Validated Sim Used Before | Validated New Application | Expand Sim & Validate | New Simulation |
| 3 Software Development | No Software Required | Data Reduction or Existing | Data Collection Real-Time S/W | Test Driver Integration | New Test Driver Real-Time S/W |
| 4 Completeness | Comprehensive Coverage | Key Parameters Comprehensive | Mathematically Validated | Modern Test Theory Applied | New Test Methodology |
| 5 Test Environment | Full Realism Real Players | Parametric Environment | Hardware & HWIL Simulation | HWIL/SWIL Environment | Sim Players or Environment |
| 6 Schedule | Easy No Uncontrolled Factors | Achievable Accounts for Uncontr Factors | Some Challenge Uncontr Factors Not Accounted | Challenging Concurrency of Components | Difficult Severe Concurrency |

# System Common Risk Scoring Matrix

| Risk Categories | | Risk Scores (0=Low, 5=Medium, 10=High) | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 1-2 | 3-5 | 6-8 | 9-10 |
| 1 | Technology Advancement | No New Tech or COTS | Minimum Advancement | Modest Advancement | Significant Advance | New Technology |
| 2 | Engineering Development | Completed or COTS | Prototype | HW/SW Development | Detailed Design | Concept Defined |
| 3 | Material Handling | Routine Done Before | No Hazards | HAZMAT Experienced | HAZMAT Change Proc | New HAZMAT Handling |
| 4 | Information Systems | Existing/COTS or None | Integrate COTS Components | Large Network or Diverse HW | New Network Topology | Design & Dev New Component |
| 5 | Consumables Management | Automated Experienced | Automated Similar | Manual or New Automation | Expand System Experience | New Area |
| 6 | Schedule | Easy | Achievable | Some Challenge | Challenging Risky Path | Difficult Critical Path |

# Risk Error Bands